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Zinc Recycling in the United States in 1998

By Jozef Plachy

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FLOW STUDIES FOR RECYCLING METAL COMMODITIES IN THE UNITED STATES

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FOREWORD

As world population increases and the world economy expands, so does the demand for natural resources. An accurate assessment of the Nation's mineral resources must include not only the resources available in the ground but also those that become available through recycling. Supplying this information to decisionmakers is an essential part of the USGS commitment to providing the science that society needs to meet natural resource and environmental challenges.

The U.S. Geological Survey is authorized by Congress to collect, analyze, and disseminate data on the domestic and international supply of and demand for minerals essential to the U.S. economy and national security. This information on mineral occurrence, production, use, and recycling helps policymakers manage resources wisely.

USGS Circular 1196, "Flow Studies for Recycling Metal Commodities in the United States," presents the results of flow studies for recycling 26 metal commodities, from aluminum to zinc. These metals are a key component of the U.S. economy. Overall, recycling accounts for more than half of the U.S. metal supply by weight and roughly 40 percent by value.

Charles G. Groat
Director

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FIGURES

TABLE

CONVERSION FACTORS

Multiply	By	To obtain
metric ton (t, 1,000 kg)	1.102	short ton (2,000 pounds)

For temperature conversions from degrees Celsius (°C) to degrees Fahrenheit (°F), use the following:

$$°F = (1.8 \times °C) + 32$$

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ABSTRACT

In 1998, about 426,000 metric tons (t) of zinc scrap was consumed in the United States; more than three-fourths (344,000 t) was new scrap, and the remainder (82,000 t) was old scrap. The main sources for old scrap were brass and bronze scrap, galvanizing residues, die-casting scrap, zinc sheet, and flue dust from steelworking electric arc furnaces (EAF's).

Old scrap was a small part of the supply because many uses of zinc are dissipative, long term, or not conducive to economic collection and recycling. In 1998, about 23 percent of zinc products were made for dissipative uses. The recycling efficiency of old scrap was about 19 percent.

Zinc in low concentrations is generally considered to be nontoxic. Consequently, recycling of zinc is driven primarily by the production cost of primary metal and the price of zinc and only to a lesser extent by environmental considerations. Because of the Government-mandated collection of flue dust, the only old zinc scrap that has an established system for collection and processing is EAF dust.

In recent years, new technology to dezinc galvanized steel has been developed. It should increase the relatively low recycling rate of old zinc scrap. The total zinc scrap recycling rate in 1998 was estimated to be 27 percent, although it may be higher. Future technical and economic developments will increasingly favor the recycling of zinc, thereby enhancing the sustainability of primary zinc production.

INTRODUCTION

The purpose of this report is to show trends in consumption, loss, and recycling of zinc in the United States in 1998 to illustrate the extent to which zinc was recycled (fig. 1, table 1). The flow diagram in figure 1 shows the quantity of zinc present at different stages of recycling and use. As easily minable deposits become exhausted and the costs of primary zinc production and waste disposal increase, the recycling of secondary materials plays an ever-increasing role in the sustainability of natural resources.

BACKGROUND

Zinc is a bluish-white metal with a melting point of about 420°C and a boiling point of 907°C. The low melting point permits low-temperature casting, and the low boiling point is an important factor in purifying the metal by distillation and in producing high-purity metal dust and zinc oxide. Many minerals contain zinc, but sphalerite (zinc sulfide) is by far the most common zinc mineral. Mined ore is usually concentrated to about 55 percent zinc content at the mill and shipped to smelters. Concentrates are reduced to zinc metal by electrolytic deposition from a sulfate solution or by distillation in retorts or furnaces (Jolly, 1992).

Measured in quantity produced, zinc is the fourth most important metal in the world after iron, aluminum, and copper. Although zinc was first produced in China in the 1st century A.D., it was not until the 18th century that it entered commercial production in Europe. In the early years, the principal uses of zinc were in sheet for building applications, in brass, and, to a lesser extent, in hot-dip galvanizing (immersion of steel or iron in molten zinc to form a coating to protect against corrosion).

During the 1930's, the use of zinc alloy castings became increasingly important with the rapid development of mass production, particularly of cars and appliances. By the 1940's, galvanizing became the dominant use (Jolly, 1997, p. 108). In 1998, an estimated 55 percent of zinc metal was used in galvanizing, followed by zinc-based alloys (19 percent) and brass and bronze (13 percent). The pattern of end uses of slab zinc (fig. 2) has a direct effect on the production and consumption of secondary zinc.

GLOBAL SOURCES OF ZINC ORE

Zinc was extracted from 20 mines in 7 States by 8 mining companies in 1998 (Plachy, 2000a). The United States accounted for 10 percent of world production; other leading producers were Australia, Canada, China, and Peru. The Red Dog Mine, which was operated by Cominco Alaska, Inc., produced more than one-half of the U.S. total zinc in concentrate, which amounted to 755,000 t in 1998 (Plachy, 2000b). Since the Red Dog Mine was opened in 1989, U.S. mine production has greatly exceeded the capacity of the three existing U.S. primary smelters, which totaled 234,000 t in 1998.

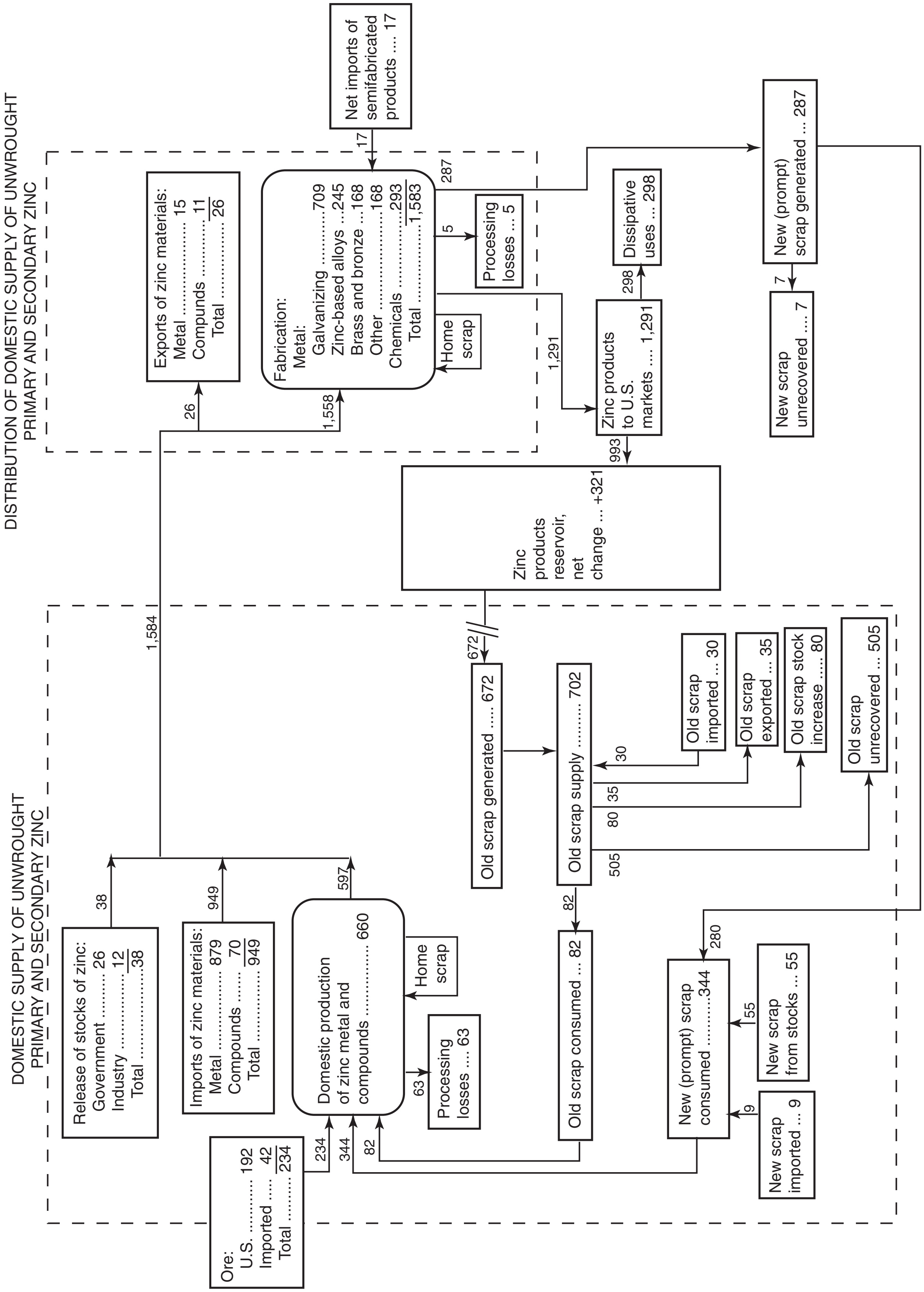

Figure 1. U.S. zinc materials flow in 1998. Values are in thousands of metric tons of contained zinc. Sources of data are described in the section titled "Sources of Zinc Scrap."

Table 1. Salient statistics for U.S. zinc scrap in 1998.
[Values in thousands of metric tons of contained zinc, unless otherwise specified]

Old scrap:	
Generated[1]	672
Consumed[2]	82
Value of old scrap consumed[3]	$71 million
Recycling efficiency[4]	19 percent
Supply[5]	702
Unrecovered[6]	505
New scrap consumed[7]	344
New-to-old-scrap ratio[8]	81:19
Recycling rate[9]	27 percent
U.S. net exports of scrap[10]	5
Value of U.S. net exports of scrap[11]	$12 million

[1]Zinc content of products theoretically becoming obsolete in the United States in 1998. Total consumption excludes dissipative uses.

[2]Zinc content of products that were recycled in 1998.

[3]The value of zinc scrap in 1998 was about $865/t contained zinc.

[4](Old scrap consumed plus old scrap exported) divided by (old scrap generated plus old scrap imported plus any old scrap stock decrease or minus any old scrap stock increase).

[5]Old scrap generated plus old scrap imported plus old scrap stock decrease.

[6]Old scrap supply minus old scrap consumed minus old scrap exported minus old scrap stock increase.

[7]Including new (prompt) industrial scrap but excluding home scrap.

[8]Ratio of quantities consumed, in percent.

[9]Fraction of the apparent metal supply that is scrap, on an annual basis.

[10]Trade in scrap is assumed to be principally in old scrap. Net exports are exports of old scrap minus imports of old scrap.

SOURCES OF ZINC SCRAP

A small amount of scrap is generated during the production and processing of zinc (new scrap), most of which is easily recovered and recycled. Scrap generated only at the end of the useful life of the product into which it is incorporated (old scrap) is more difficult to recover; consequently, only a small portion is recycled. Until 1993, nearly all zinc used in galvanized steel products was lost either in landfills or in slag at steel scrap processing plants.

In recent years, zinc has been recovered from flue dust, and new technology to dezinc galvanized steel has been developed. This new dezincing process should increase the relatively low recycling rate of old zinc scrap, thereby enhancing the sustainability of primary zinc production. The total zinc scrap recycling rate in 1998 was estimated to have been 27 percent (table 1). The balance of supply was primary material.

Many metallic and virtually all chemical uses of zinc are essentially dissipative. Given the long life cycles for zinc products, a large amount of metallic zinc is still in use. Apart from what is now being recovered, small amounts of zinc-containing objects still end up in slag or landfills, from which an unknown amount of zinc may be leached by acidic water. A much smaller fraction of metallic zinc is vaporized and discharged to the atmosphere.

In 1998, about 426,000 t of zinc scrap was consumed in the United States; more than three-fourths (344,000 t) was new scrap, and the remainder (82,000 t) was old scrap. The value of zinc in recycled scrap (old and new scrap consumed plus old scrap stock increase) was $437 million in 1998. In 1990, the main sources for secondary zinc were as follows (Pocket Guide to World Zinc, 1996): brass and bronze scrap, 32 percent; galvanizing residues, 23 percent; die-casting scrap, 16 percent; zinc sheet, 10 percent; and flue dust from steelworking electric arc furnaces (EAF's), 8 percent. Percentages were probably similar in 1998. During 1998, about 795,000 t of zinc was unrecovered from old scrap or dissipated. The recycling efficiency of old scrap was about 19 percent (table 1).

Most of the data in figure 1 were collected by the U.S. Geological Survey (USGS). The domestic supply of primary and secondary zinc shown in figure 1 is estimated from monthly and annual USGS surveys of domestic producers, data on sales from the U.S. Government's National Defense Stockpile, import/export data compiled by the U.S. Census Bureau, and reported changes in producer, consumer, and merchant stocks. Reporting by producers and consumers of zinc is voluntary.

The three largest secondary zinc producers do not report consumption of secondary zinc. Consequently, data concerning fabrication, production, and consumption of new and old scrap are mostly estimates based on survey forms compiled by the USGS and various studies carried out by individuals and organizations, such as the International Lead and Zinc Study Group. The 27-percent recycling rate shown in table 1 may actually have been much higher. According to IMCO Recycling, Inc. (1999), the world's largest zinc recycler, the recycling rate for zinc in the United States could have been as high as 38 percent.

DISPOSITION OF ZINC SCRAP

Zinc in low concentrations is generally considered to be a nontoxic material. Consequently, recycling of zinc is driven primarily by the production cost of primary metal and the price of zinc and only to a lesser extent by environmental considerations. Because of the Government-mandated collection of flue dust, the only secondary zinc that has an established system for collection and processing is EAF dust. Collection of other zinc scrap is done by either public organizations or private companies.

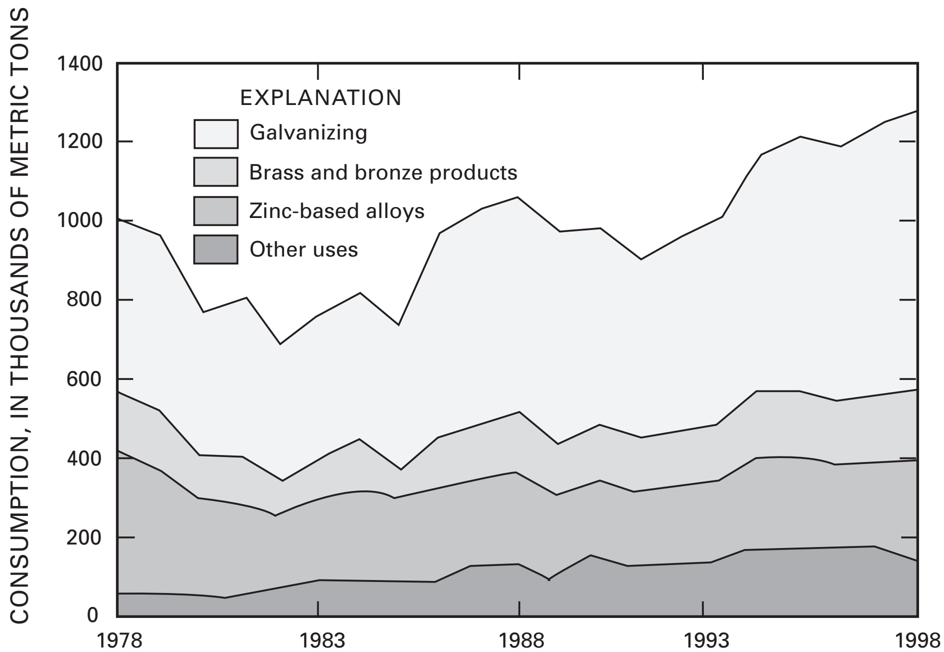

Figure 2. U.S. slab zinc consumption by end-use sector from 1978 through 1998.

OLD SCRAP

Old scrap consists of used zinc products in the form of zinc metal or alloys, which have been discarded because of wear, damage, or obsolescence. This category includes die-castings, automobile shredder scrap, engraver plates, brass and bronze products, rolled zinc from roofing and gutters, dust and sludges from ironmaking and steelmaking, and contaminated waste solutions (mine waste, rinse effluents, waste plating solutions, and contaminated surface waters). In the past, the types of old scrap that were processed were limited by the ease of collection and the narrow range of composition. Therefore, only small amounts of old scrap were recycled.

Environmental mandates that were passed in the 1980's broadened the types of old scrap collected by the recyclers by adding effluent zinc from recycling of galvanized steel scrap and zinc recovered from burning rubber tires. Despite Government-mandated efforts to protect the environment, only about 12 percent of the total zinc consumption in the United States was derived from old scrap in 1998. Old scrap was a small part of the supply because many uses of zinc are dissipative, long term, or not conducive to economic collection and recycling. In 1998, about 23 percent of zinc products were made for dissipative uses; dissipation can be either rapid (fertilizers, animal feed, fungicides, pharmaceuticals) or long term (corrosion of galvanized surfaces, rubber tire abrasion, flaking paint). Large amounts of zinc products are still in circulation because their usefulness may last 100 years. These products include zinc used in galvanizing and, in smaller quantities, in zinc-based alloys, brass, and bronze. About 68 percent of U.S. zinc products made in 1998 will eventually be available as old scrap, but only a small portion of them will be recycled.

NEW SCRAP

New or prompt scrap is defined as that generated in manufacturing processes and consumed at plants other than where generated. Although the amount of new zinc scrap generated, which is estimated to have been 287,000 t in 1998, is much smaller than the amount of old scrap generated (672,000 t), it constitutes more than three-fourths of consumed recycled zinc. Most of the new scrap is produced during fabrication before it becomes part of a product; therefore, it is easily collected for recycling. New scrap consists mostly of galvanizing residues that comprise a wide range of different materials, including ashes, flux residues, and top and bottom drosses; all have a very high content of zinc metal (Radiant Corp., 1976, p. 182).

OLD SCRAP RECYCLING EFFICIENCY

The recycling efficiency of old zinc scrap for 1998 in the United States is estimated at 19 percent; compared with the recycling efficiency of other metals, that of zinc is very low because nearly all chemical uses of zinc are virtually dissipative and because galvanized products have long life cycles before the zinc can be recovered. Like zinc alloys, including brass and bronze, galvanized steel is potentially a large source of secondary zinc. Because zinc is not a toxic metal, the increased recycling efficiency of zinc depends more on improving the technology to dezinc galvanized steel than on environmental protection requirements.

INFRASTRUCTURE OF ZINC SCRAP

Although the exact number of recycling facilities is not known, the zinc recycling industry is dominated by IMCO Recycling, Inc., and Zinc Corporation of America. Together, they treated nearly three-fourths of all U.S. secondary zinc in 1998. Most of the recycling plants were in Michigan, Pennsylvania, Tennessee, and Texas.

Because most zinc metal is used for corrosion protection of iron and steel, the largest portion of recycled zinc is supplied by steel industries either as galvanizing residues or as flue dust. Galvanizing residues contain between 90 and 95 percent zinc and 5–10 percent other metals. Depending on the steel type and the galvanizing process, between 10 and 40 percent of the total zinc consumed ends up in residues. Zinc, which is metallurgically combined with steel during galvanizing, cannot be easily separated from galvanized steel scrap. It is usually recovered from flue dust generated during reprocessing of steel scrap. This dust contains an average of 20 percent zinc, which is generally recovered as crude zinc oxide for zinc metal production.

Because the largest consumer of zinc is the steel industry, the largest consumers of galvanizing residues and flue dust are located near large steelworks. Collection of secondary zinc is usually based on long-term agreements between steel producers and secondary zinc consumers.

As is the case with galvanized steel, zinc die-cast components enter the recycling stream as a function of the number and type of products used. Old die-cast components provide high metal recovery, but the recovery of the products in which they are contained is typically low.

About one-third of U.S. consumption of zinc in 1998 came from domestic primary and secondary production. The balance was supplied by imports, mostly from Canada. Trade in zinc scrap was relatively small compared with trade in zinc concentrate and zinc metal. Most of the zinc scrap exports were shipped to Asia, primarily to Taiwan. In 1998, more than 90 percent of scrap imports came from Canada.

PROCESSING OF ZINC SCRAP

Zinc can be recycled again and again without loss of its original properties. Its low melting and boiling points make zinc relatively easy to recycle. The main sources for secondary zinc, listed in decreasing order of use, are brass and bronze scrap, galvanizing residues, die-casting scrap, zinc sheets, and flue dust from steelworking electric arc furnaces (EAF's). Processing methods for these scrap materials are described below, as is a new dezincing process that should increase the recycling of galvanized steel scrap.

BRASS AND BRONZE SCRAP

With its high value and high copper content, brass and bronze scrap is recycled almost exclusively by the brass and copper industries. Effectively, this means that zinc used in brass leaves the zinc recycling circuit and is completely recycled within the brass/copper circuit. However, it is included in the materials flow depicted in figure 1. "It is a common practice to boil secondary zinc alloys [in muffle furnaces or retorts] and evaporate zinc away from the alloying elements" (Schau, no date). The zinc vapor can be purified in a distillation column to produce refined zinc metal.

GALVANIZING RESIDUES

Because of environmental restrictions and the high content of entrained zinc metal, galvanizing residues (which comprise top and bottom drosses, skimmings, and ashes) are the second most commonly recycled zinc scrap. Most galvanizing residues are cast into slabs as discussed below, but some other processing methods are used.

Combining drosses with fluxes.—Galvanizers' drosses are metallic alloys of iron and zinc plus some unalloyed zinc and other metals, mainly aluminum, lead, and tin. The bottom dross consists mainly of iron and zinc. Because it is heavier than the molten zinc, it sinks to the bottom of the galvanizing pots. The light, top dross contains primarily zinc and aluminum with small amounts of iron, lead, and tin. Both these drosses can react with various fluxes to release the entrapped metallic zinc, which is cast into slabs for subsequent use by secondary zinc smelters.

Treating skimmings and ashes.—Skimmings and ashes are formed by oxidation on the surface of galvanizing baths when no flux is used. High-grade skims are used directly by secondary producers. Medium- and low-grade skims generally undergo an intermediate reduction-distillation-pyrometallurgical step to upgrade the zinc content before treatment, or they are leached with acid, alkaline, or ammoniacal solution to extract zinc, which is subsequently recovered as a compound by crystallization or as a salable chemical product retained in solution.

Casting galvanizing residues into slabs.—Most of the galvanizing residues are cast into slabs and fed into furnaces that are stationary, horizontal, or tilted. Most of the furnaces are fired with either natural gas or oil. Feed is placed in a retort through which a flame passes and heats up the charge to the boiling point. The fumes pass through the neck of the retort into a condenser, where they are cooled to form either metal or dust, depending on the type of condenser. Recovery efficiency is very high from simple remelting but declines as the number of processing steps increases (Edwards, 1977, p. 5).

DIE-CASTING SCRAP

New die-casting scrap is recycled directly and qualifies as home scrap. Old scrap, which includes, in particular, that from shredding of cars and domestic appliances, can be used in the production of zinc dust and zinc oxide and as a feedstock for smelters.

ZINC SHEETS

Zinc sheets are generally old scrap from roofs, cladding, gutters, and downspouts, together with some "cut-offs" from the use of new sheet. This material is the most sought after by zinc recyclers, because it can be readily used by secondary or primary zinc producers.

EAF DUST

The use of zinc for galvanizing has grown very substantially in the last 40 years, but owing to the long life of galvanized products, this source has only recently appeared in substantial quantities as scrap. After reauthorization of the Resource Conservation and Recovery Act in 1984, which substantially raised the disposal cost of EAF dust, the recycling of EAF dust is estimated to have increased to about 75 percent in 1998 from 30 percent in 1984. Inclusion of EAF dust in the hazardous waste list created a market for approximately 500,000 t per year of flue dust (Consolidated Materials Brokers, L.L.C., 1998). Zinc content ranges from about 5 percent to nearly 40 percent zinc (average about 20 percent), and the dust contains small amounts of hazardous constituents, including cadmium, chromium, and lead.

The first treatment of flue dust is usually carried out close to secondary steel plants. The predominant technology used for the recovery of zinc from EAF dust is the Waelz kiln process. The EAF dust is mixed with coal and flux and fed to the kiln, where materials roll along the inside slope. Occasionally, energy provided by coal combustion is supplemented by natural gas or oil combustion via a burner at the discharge end of the kiln. The feed is reducing and oxidizing simultaneously in the kiln, thus generating two marketable products—a mixed zinc/lead oxide and an inert iron-rich slag. Most of the crude zinc/lead oxide, which contains about 55 percent zinc, is reused by the Zinc Corporation of America at its Monaca, Pa., plant for production of zinc metal and refined oxide. Slag, which contains between 30 and 35 percent iron, is sold as road base, anti-skid agent, portland cement additive, and an aggregate in highway blacktop (Kern and Mahler, 1987, p. 8).

GALVANIZED STEEL SCRAP

Metal Recovery Technologies, Inc., installed a pilot plant in East Chicago, Ind., that converted galvanized steel scrap into clean scrap for steelmaking and zinc solution. The new process used in this plant consisted of dissolving the zinc coating from scrap in a hot, caustic solution and recovering the zinc from the solution electrolytically. Because the electrolyte was reused, waste was minimal compared with waste caused by processing of flue dust (Argonne National Laboratory, Transportation Technology Research and Development Center, 1998).

OUTLOOK

The changes in end-use patterns of zinc and the overall increase in consumption mean that considerably increased amounts of zinc will be available for recycling, despite the long lifetime of zinc products. As with other materials, future technical and economic developments, such as efficient separation of zinc from galvanized steel, will increasingly favor the recycling of zinc.

Environmental considerations, technological advances, and the economics of primary and secondary production are the major reasons for increased recycling of all metals. In the past, only new zinc scrap was recycled. As time progressed, old scrap was recycled, and old scrap recycling efficiency began to increase. Although zinc is not a hazardous material, high concentrations of it could harm the environment. The nature of the principal uses of zinc and established recycling circuits, however, ensure that zinc is rarely an environmental threat.

Past patterns of use indicate that increasing amounts of zinc will be used for galvanizing. Therefore, the development of economically efficient recycling of galvanized scrap should increase the recycling rate of old scrap. With the growing availability of valuable secondary materials and increased efficiency of zinc recovery, the amount of zinc coming from secondary sources should increase steadily. An increase or decrease of recycling capacity will depend mainly on the relative cost of recycling and changes in regulations governing disposal of secondary zinc.

The recycling rate of zinc, however, will probably not approach that of some of the other major metals because many uses of zinc are dissipative or nonrecoverable. For example, zinc used in fertilizers or animal feed is essentially unrecoverable, and zinc in paints or in rubber products has, at best, only limited recoverability (Munford, 1998).

Despite a relatively low recycling rate, the recycling industry enhances the sustainability of zinc production by reducing the need for primary production, thereby saving energy and extending the longevity of natural resources.

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APPENDIX—DEFINITIONS

apparent consumption. Primary plus secondary production (old scrap) plus imports minus exports plus adjustments for Government and industry stock changes.

apparent supply. Apparent consumption plus consumption of new scrap.

brass. An alloy of copper and zinc that may contain other elements such as aluminum, iron, manganese, nickel, tin, and lead.

bronze. An alloy of copper and tin that may contain other elements such as aluminum, silicon, and zinc.

dissipative use. A use in which the metal is dispersed or scattered, such as paints or fertilizers, making it exceptionally difficult and costly to recycle.

home scrap. Scrap generated as process scrap and consumed in the same plant where generated.

hot-dip galvanizing. Immersion of steel or iron in molten zinc to form a coating to protect against corrosion.

new scrap. Scrap produced during the manufacture of metals and articles for both intermediate and ultimate consumption, including all defective finished or semifinished articles that must be reworked. Examples of new scrap are borings, castings, clippings, drosses, skims, and turnings. New scrap includes scrap generated at facilities that consume old scrap. Included as new scrap is prompt industrial scrap—scrap obtained from a facility separate from the recycling refiner, smelter, or processor. Excluded from new scrap is home scrap that is generated as process scrap and used in the same plant.

new-to-old-scrap ratio. New scrap consumption compared with old scrap consumption, measured in weight and expressed in percent of new plus old scrap consumed (for example, 40:60).

old scrap. Scrap including (but not limited to) metal articles that have been discarded after serving a useful purpose. Typical examples of old scrap are electrical wiring, lead-acid batteries, silver from photographic materials, metals from shredded cars and appliances, used aluminum beverage cans, spent catalysts, and tool bits. This is also referred to as post-consumer scrap and may originate from industry or the general public. Expended or obsolete materials used dissipatively, such as paints and fertilizers, are not included.

old scrap generated. Metal content of products theoretically becoming obsolete in the United States in the year of consideration, excluding dissipative uses.

old scrap recycling efficiency. Amount of old scrap recovered and reused relative to the amount available to be recovered and reused. Defined as (consumption of old scrap (COS) plus exports of old scrap (OSE)) divided by (old scrap generated (OSG) plus imports of old scrap (OSI) plus a decrease in old scrap stocks (OSS) or minus an increase in old scrap stocks), measured in weight and expressed as a percentage:

$$\frac{\text{COS} + \text{OSE}}{\text{OSG} + \text{OSI} + \text{decrease in OSS or} - \text{increase in OSS}} \times 100$$

old scrap supply. Old scrap generated plus old scrap imported plus old scrap stock decrease.

old scrap unrecovered. Old scrap supply minus old scrap consumed minus old scrap exported minus old scrap stock increase.

price. Based on the unit value of zinc in materials.

primary zinc. Zinc derived from ore.

recycling. Reclamation of a metal in usable form from scrap or waste. This includes recovery as the refined metal or as alloys, mixtures, or compounds that are useful. Examples of reclamation are recovery of alloying metals (or other base metals) in steel, recovery of antimony in battery lead, recovery of copper in copper sulfate, and even the recovery of a metal where it is not desired but can be tolerated—such as tin from tinplate scrap that is incorporated in small quantities (and accepted) in some steels, only because the cost of removing it from tinplate scrap is too high and (or) tin stripping plants are too few. In all cases, what is consumed is the recoverable metal content of scrap.

recycling rate. Fraction of the apparent metal supply that is scrap on an annual basis. It is defined as (consumption of old scrap (COS) plus consumption of new scrap (CNS)) divided by apparent supply (AS), measured in weight and expressed as a percentage:

$$\frac{\text{COS} + \text{CNS}}{\text{AS}} \times 100$$

scrap consumption. Scrap added to the production flow of a metal or metal product.

secondary zinc. Zinc derived from or contained in scrap.

slab zinc. A general term for commercial zinc cast in various shapes and sizes.